Massive Air and Stream Temperature Sensor Networks for Studying Microclimatic Variation In Mountain Landscapes

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PIBO Fish & Aquatic Ecology Unit

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Introduction

Climate change is motivating extensive research to understand potential responses in terrestrial and aquatic ecosystems. Ongoing efforts to downscale climate models are improving the resolution at which climate data are available, but outputs from even the latest regional climate models are coarse relative to the scales at which ecological processes operate and landscapes and natural resources are managed (Wiens and Bachelet 2009). Inexpensive digital temperature sensors and remote sensing technology now facilitate collecting large amounts of information for a variety of environmental attributes (Holden et al., In press; Porter et al. 2005; Isaak and Horan 2011). Within the northwest U.S., efforts are underway to develop massive regional air and stream temperature sensor networks to understand microclimatic variation in mountainous terrain (Figures 1 and 2).

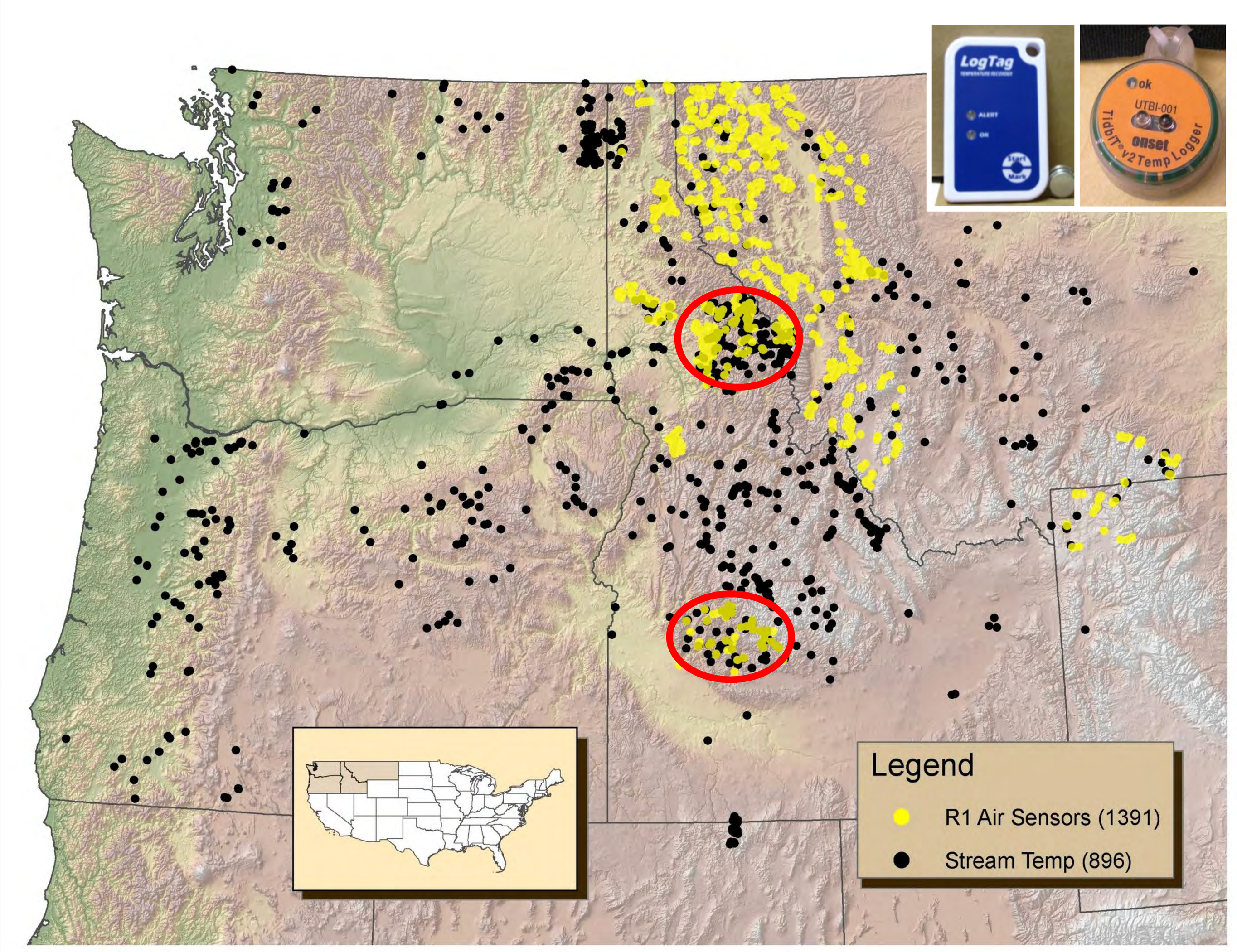


Figure 1. Locations of air and stream temperature sensors deployed by multiple agencies in dense regional networks to understand microclimatic variation in mountainous terrain. Inset photos show examples of temperature sensors. Units cost $20 - $100 and have memory capacities and battery lives of 3 – 5 years. Red circles denote river basins where sensor networks were co-located.

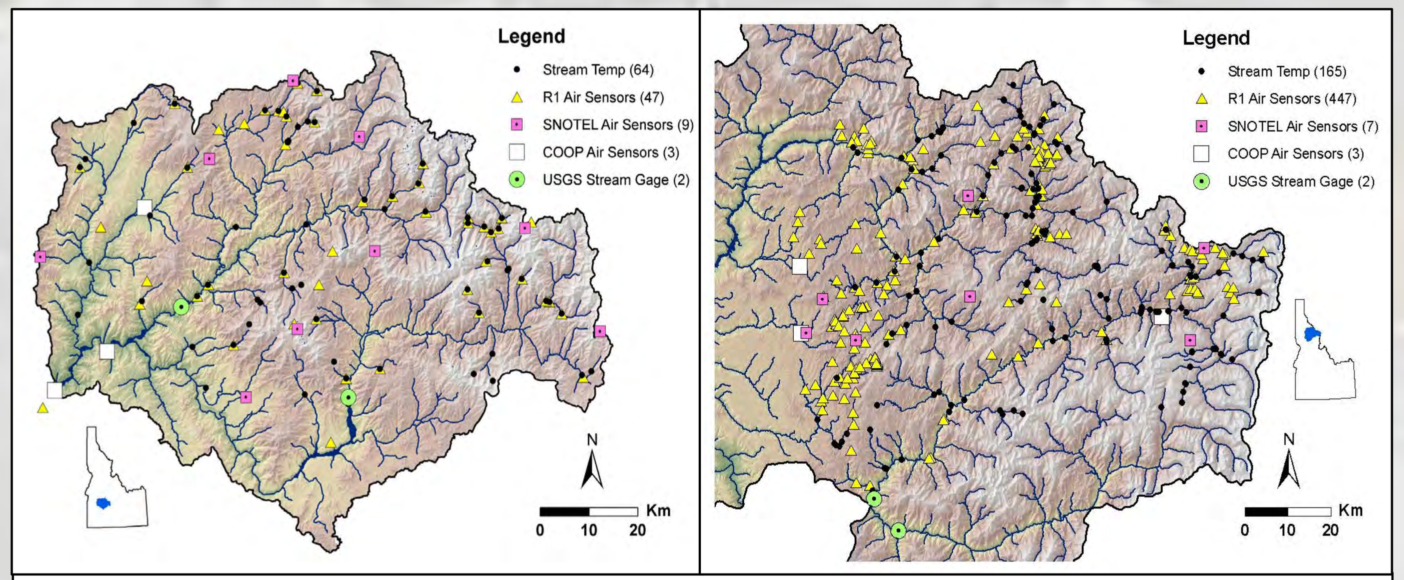


Figure 2. Air and stream temperature sensor networks were densified and co-located within two large river basins (> 5,000 km²) with contrasting physiographic characteristics (Boise River basin in southern Idaho (left panel) and the Lochsa/North Fork Clearwater River basin in northern Idaho (right panel)) to enable detailed examination of temperature interactions.

High-Resolution Temperature Mapping

Data from air temperature sensor networks can be used to empirically downscale observational or gridded climate data sets precisely in mountainous terrain (Figure 3; left panel). Spatial statistical kriging techniques for streams (Ver Hoef and Peterson 2010) can be applied to stream sensor network data to interpolate continuous temperature surfaces throughout river networks (Figure 3; right panel). Moreover, because temperature sensors record multiple measurements each day, changes in spatial temperature patterns can be examined over a variety of time intervals, from hourly to annual.

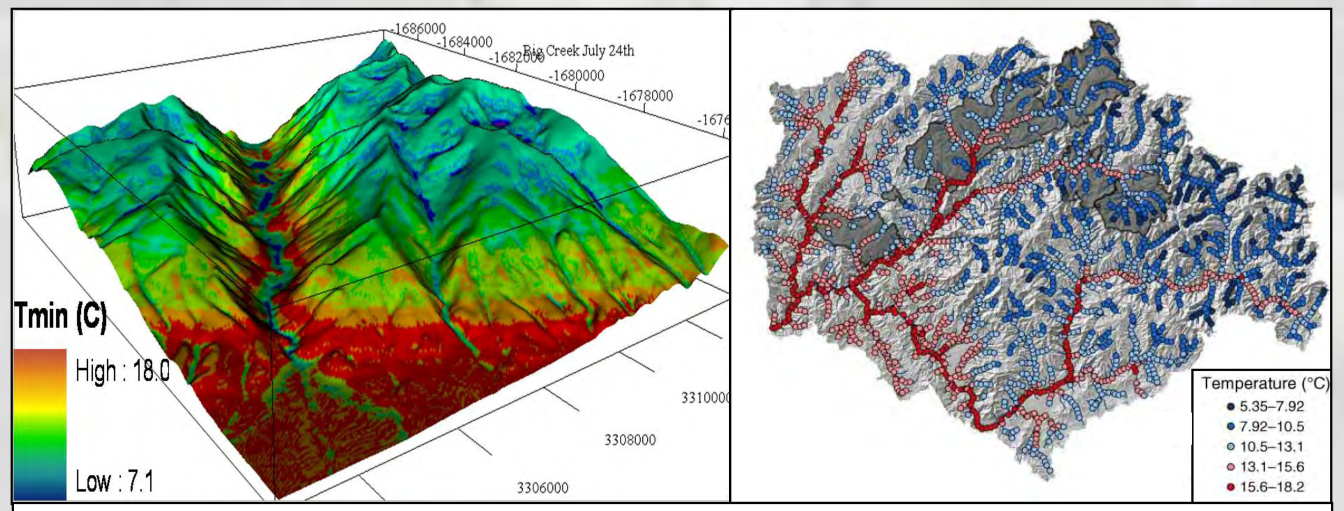
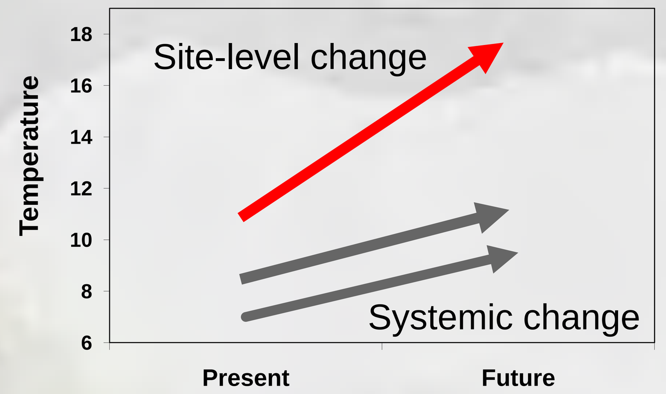


Figure 3. Left panel. Predicted July 23, 2009 minimum air temperatures draped over a three-dimensional surface of the Big Creek drainage in western Montana using EOF analysis methods described in Holden et al. (in press). Notice the pools of cold air that accumulate in depressed topographic regions on ridges and stream valleys.

Right panel. Mean summer stream temperatures predicted for 2006 from stream kriging in the Boise River network. Notice strong gradient towards warmer temperatures from right (high elevations) to left (low elevations). The stream temperature model used to derive the temperature map accounted for 93% of the variation in temperatures measured at 518 sites and had an average prediction error of 0.74 °C (Isaak et al. 2010).

Research Questions

High resolution temperature networks and interpolated surfaces make it possible to explore many questions pertaining to microclimatic variation in mountains. With regards to climate change, for example, microclimatic temperature surfaces could be linked to regional (or global) climate models to simulate warming effects on local environmental conditions for plant and animal species. Such studies could also provide key information regarding the relative importance of systemic temperature changes versus local variation (Figure 4).



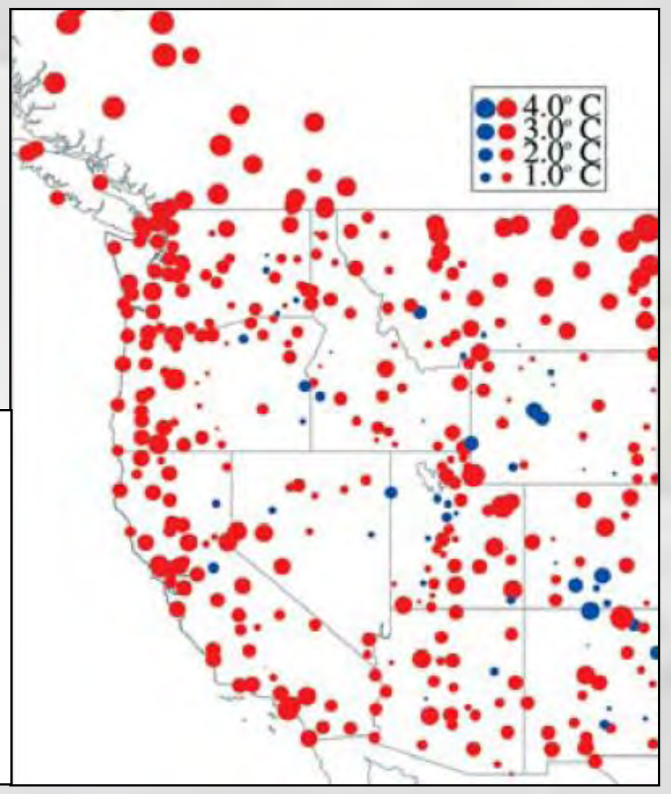
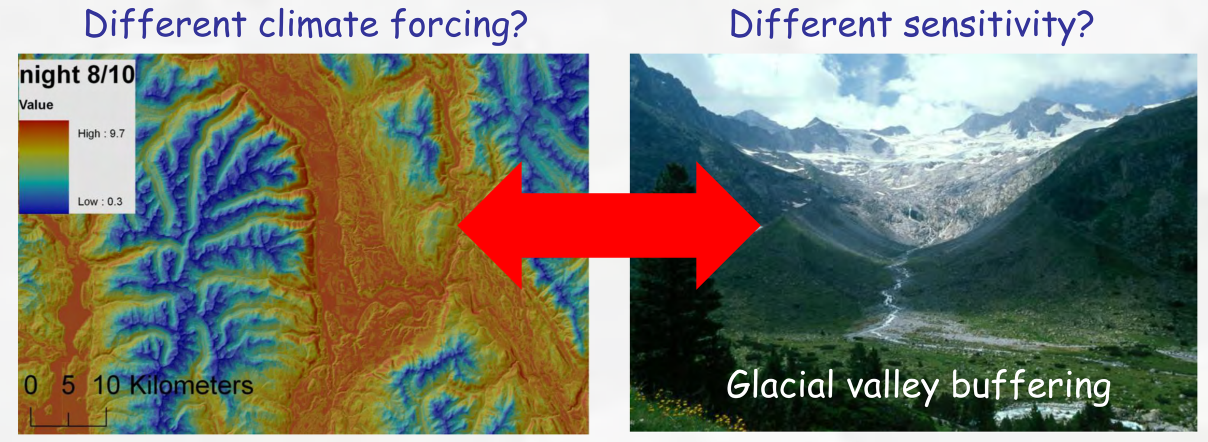


Figure 4. Average trend among all sites equates to systemic change whereas local deviations equate to site-level change. These distinctions are well illustrated by spatial variation in air temperature trends measured at weather stations across the western U.S. from 1950-1997 (Mote et al. 2005). Similar heterogeneity is expected at smaller spatial scales and is likely to be enhanced in complex mountain topographies.

Site-level variation could arise from differences in climate forcing (e.g., air temperatures increase faster in some areas than others) or differences in sensitivity of landscape elements (e.g., some streams are less buffered by groundwater and warm more in response to air temperature increases). Disentangling these two mechanisms and attribution of factors contributing to sensitivity will be important for understanding how climate change affects mountain landscapes and predicting which areas, species, and habitats may be at greatest risk.



Adapted from Holden, Cushman, Crimmins and Littell (in press)

In addition to climate change research, data from dense temperature sensor networks could facilitate research regarding:

- How physiography and topoclimatic variation in surface air temperatures (e.g. cold air drainage) influence stream temperature variation.
- Sensor densities, sample sizes, and network configurations necessary for accurately describing fine-scale variation in temperatures.
- Development of empirical or physical equations that facilitate historical and future downscaling in the absence of *in situ* data.
- Validation and local calibration of regional or global climate models, physically and empirically-based temperature models, and fire-behavior models.
- High-resolution bioclimatic distribution models for plants and animals.

Inexpensive and reliable temperature sensors, deployed in dense networks and coupled with new spatial analytical techniques, are rapidly increasing the ability to measure and model microclimatic conditions in mountain landscapes. Development of similarly dense networks, strategically coordinated with existing long-term monitoring networks (e.g., SNOTEL, RAWS, COOP) and arrayed across a range of mountain environments in the western U.S. or globally, could provide valuable insights regarding how ecosystems in mountain environments are structured and may respond to climate change. Moreover, similar advances in sensing technology are occurring for precipitation, snowmelt timing, and stream flow, among others (Porter et al. 2005). Integrating better information about all these factors promises a more comprehensive understanding of material and energy flows through mountain landscapes in the future.

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